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Estimating Winds and Waves from SAR Under Typhoon Conditions

Dr. Christopher Wackerman
1200 Joe Hall Drive
P.O. Box 990
Ypsilanti MI 48197
phone: (734) 480-5413 fax: (734) 480-5367 email: chris.wackerman@gd-ais.com

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LONG-TERM GOALS

The long-term goal of this program is to be able to utilize SAR imagery to improve predictions of storm tracks and storm strength at landfall (we use storms as stand-in for hurricanes, typhoons, etc.). This will be done with a system that uses SAR imagery of the storm at sea to estimate wind and wave conditions within the storm, then utilizes these estimates to re-set storm model parameters so that the predicted winds/waves at the time of the SAR imagery match the actual winds/waves. The goal is that the model predictions derived with the re-set parameters will be improved over those that do not have the SAR estimates.

OBJECTIVES

There are three objectives in this program.

(1) Modify the existing General Dynamics Advanced Information Systems (GDAIS) wind vector tool to handle the higher wind states in storms and generate accurate maps of wind vectors within the storm.

(2) Modify the existing GDAIS wave spectra tool to handle the higher wind/wave states of storms and generate accurate maps of wave height statistics within the storm.

(3) Work with storm modelers to determine the best approach for incorporating the SAR-derived wind and wave information into the model predictions.

APPROACH

(1) Modification of the wind vector tool

Under the NOAA/NESDIS funded Alaska SAR Demonstration Project, GDAIS has developed an algorithm for estimating wind vectors from SAR imagery (Wackerman et al., 2003). Wind directions come from a projection-based method to find linear features in the SAR image that are aligned with the wind. Wind speed comes from inverting a physics-based forward model for the RCS that uses the two-scale model to predict mean RCS values (Wackerman et al., 2002). The forward RCS model already

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has a tilted Bragg scattering term (so there is no linearization of the tilted ocean surfaces), a hydrodynamic modulation term that induces an upwind, downwind asymmetry as seen in observations, a spectral scattering term for wave facets tilted toward the radar, and a choice of possible wave spectral models to use. This model has already been validated for C-VV and C-HH data (Wackerman et al., 2002) and is currently being validated for X-band VV and HH data as part of a set of airborne SAR collections. First we propose putting into this forward RCS model a wave height modulation model appropriate for typhoon conditions; i.e. a model where the wave heights grow appropriately with the strong winds. Second, we currently assume a zero-mean Gaussian distribution for the wave facet tilts where the standard deviation is modeled based on wind speed. The model for slope variance with respect to wind will need to change for typhoon conditions, and we will need to examine whether the Gaussian assumption is still correct (essentially whether the waves are dominantly non-linear). Theoretically the rest of the forward model should work as is. We will compare the resulting forward RCS model with CMOD4 and CMOD5, as well as validate it against the test set discussed below (note that we can validate the forward RCS model separate from validating the wind or wave tools).

The wind direction estimation will most probably also need to be modified to handle the smaller spatial scale of significant changes in wind direction for typhoon conditions. Currently the projection code assumes a relatively large spatial scale (~16km) for wind direction changes. We anticipate that this will be performed by changing the metric used to determine which projection has the largest variation across spatial scales (and thus represent the direction that is orthogonal to the wind vector). Currently this is done by finding the direction of maximum contrast (standard deviation divided by the mean). We may not have enough samples to generate accurate statistics over the short spatial scales, so we anticipate needed a metric based on more point-line measurements (e.g. maximum minus minimum value, or the maximum local gradient).

(2) Modification of the wave spectra tool

Also under NOAA/NESDIS funding, GDAIS has developed an automated wave spectrum estimation tool based on both linear transfer function (Wackerman, 2006) as well as a fully non-linear transfer function that iteratively finds the underlying wave spectrum from a starting assumption of no waves (thus no a priori wave information is required). We anticipate needing the fully non-linear transfer function for typhoon conditions. However this forward model has an internal wave-to-RCS transfer function that is probably not appropriate for typhoon conditions. We proposed modifying this by incorporating the forward RCS model from the wind vector tool into the wave estimation tool to allow accurate RCS modulations from typhoon-condition waves. All the non-linearity of the SAR imaging process should then work as currently implemented. This will require modifying the iteration process which uses a gradient estimate to perform a conjugate gradient search for the wave spectra that minimizes errors with the SAR image. We will need to re-derive this gradient using the new forward RCS model.

(3) Implementation into models

Working with modelers we will determine how to best utilize the SAR-derived wind and wave maps into their models. Most probably this will be done by determining the model parameters that can re-construct the SAR-derived winds/waves for the time of the image, then using these new parameters to perform model predictions.

WORK COMPLETED

We have generated a new version of the SAR wind estimation tool for hurricanes/ typhoons. This has required modifying how we smooth wind directions (instead of assuming a locally uniform field we need to assume a locally elliptical field) and incorporating a new RCS term for the higher winds (CMOD5). We have also used the wind rotation in the storm to remove the 180 degree ambiguity from the SAR winds. We have an initial comparison between SAR-derived winds and *in situ* observations (SFMR flights through the storm, buoys, winds from the QuickSCAT satellite, and ECMWF model winds) for 8 storms, and are using this to generate empirical corrections to the RCS model CMOD5 to handle apparent errors in the look angle dependence of the model.

We also had to automate a pre-processing step where we clean-up image artifacts that are from the image formation process (such as scale differences between seems and noise floor artifacts) so that they do not generate false wind directions.

RESULTS

Figure 1 shows an example of the SAR-derived winds compared to available *in situ* observations for Hurricane Helene on two days (19 and 20 Sept. 2006). The white bars are SAR-derived winds and the colored bars are from various *in situ* observations as indicated by the legend. The angle of the bar represents wind direction and the length of the bar represents wind speed. Thus we want the SAR white bars to have the same angle and length as the *in situ* colored bars. For this storm, visually the comparison is good. Figure 2 shows a more complete comparison of estimated wind directions from SAR versus *in situ* observations from QuickSCAT (the only reliable wind direction *in situ* data) over all eight storms. The RMSE in 39 degrees, compared to approximately 23 degrees RMSE for non-storm conditions. Note that bias in wind direction can be see in Figure 2; we are currently investigating whether this may be due to a systematic rotation between the ocean features used to derived wind directions and the actual surface wind.

Figure 3 shows the comparison of estimated wind speed between the SAR-derived values and the SFMR (stepped frequency microwave radiometer) flights through the storm. SFMR only estimates wind speed, but it has been highly validated and is the best *in situ* data for wind speed. There are two points in Figure 3 that have been indicated as outliers. These are due to what appears to be an error in the CMOD5 model for high winds at SAR look angles that are around 45 degrees from the wind direction. We have actually consistently seen this error in all of the storm results so far. We are using the observed RCS values as an empirical correction to CMOD5 to see if we can find an "easy" fix for these apparent errors. If we remove those outliers, the RMSE in wind speed estimation is approximately 8 m/s (versus 2 m/s being typical for non-storm conditions). However we need to be somewhat careful here since it is not clear what uncertainties may exist in the in situ observations during storms. Figure 4 plots comparisons of *in situ* data for wind speed against each other; buoy versus SFMR (left) and QuickSCAT versu SFMR (right). Note that in both cases the RMSE is actually worse then for SAR-derived wind speeds versus SFMR. Thus these initial results indicate that the SAR is at least as good (if not better) than the other *in situ* observations.

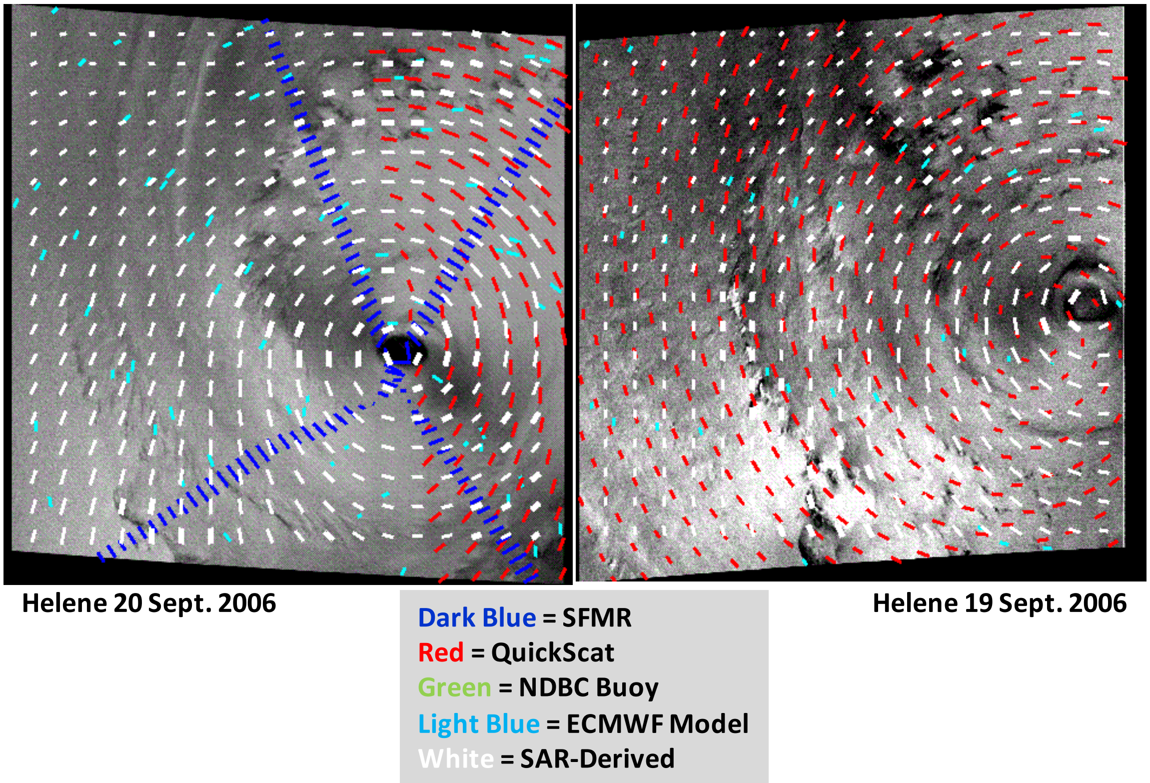


Figure 1: SAR-derived wind vectors (white bars) versus various in situ wind observations (colored bars) for two days during hurricane Helene. The angle of the bars indicates wind direction and the length indicates wind speed. Visually the SAR-derived results compare well with both SFMR (stepped frequency microwave radiometer) and QuickSCAT observations. There were no buoy observations for these dates and the SCMWF models results are not good.

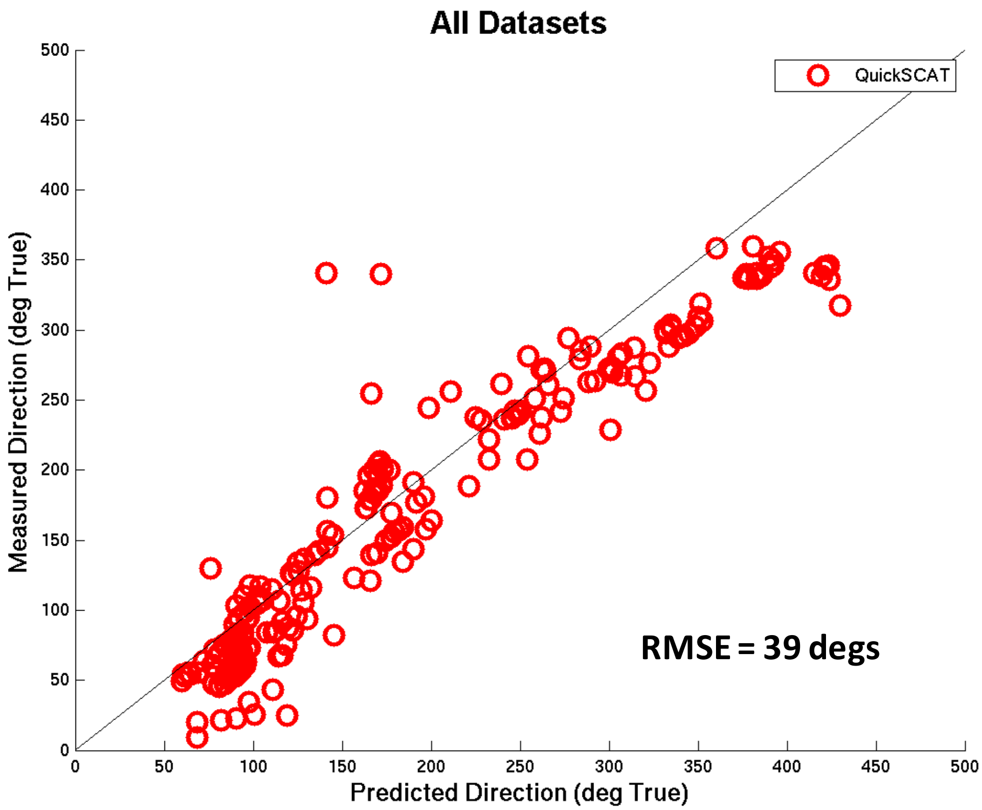


Figure 2: Results for all 8 images of SAR-derved wind direction (x-axis) versus in situ observations of wind direction from QuickSCAT (y-axis). The root-mean-squared error (RMSE) is 39 degrees versus 23 degrees for non-storm conditions. Note however that there appears to be a bias in the results that may be due to a rotation between the ocean features used for wind direction and the actual surface wind.

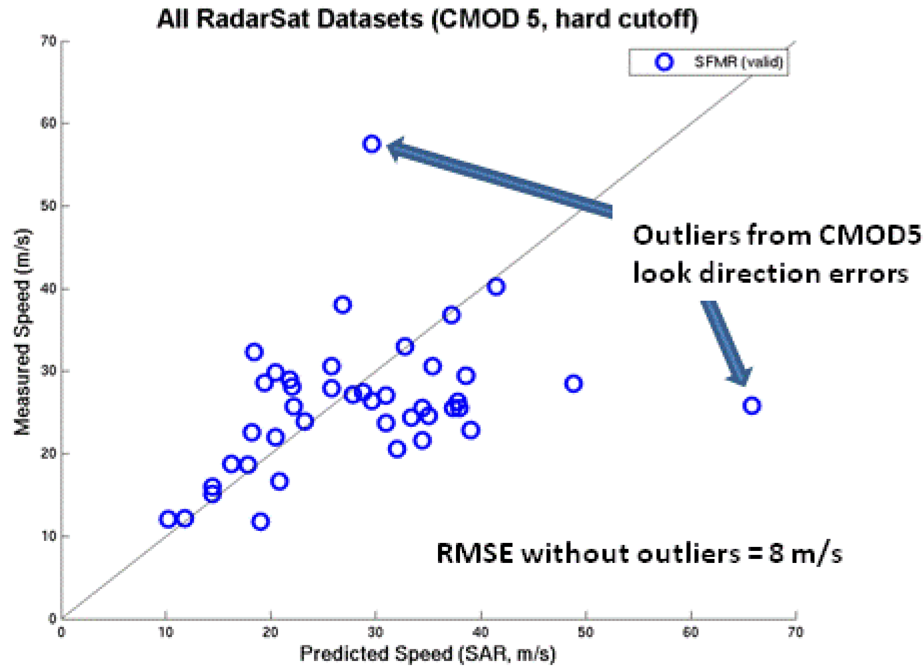
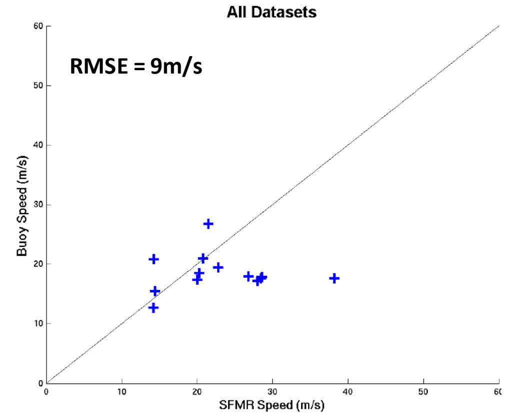


Figure 3: Comparison of SAR-derived wind speed (x-axis) versus SFMR observations (y-axis). The two outlier indicated in the figure come from an observed error in the RCS model (CMOD5) at high winds and at SAR look angles around 45 degrees from the wind direction. Without the outliers the RMSE is 8 m/s. Note that this is better than the comparison between in situ observations (see Figure 4).



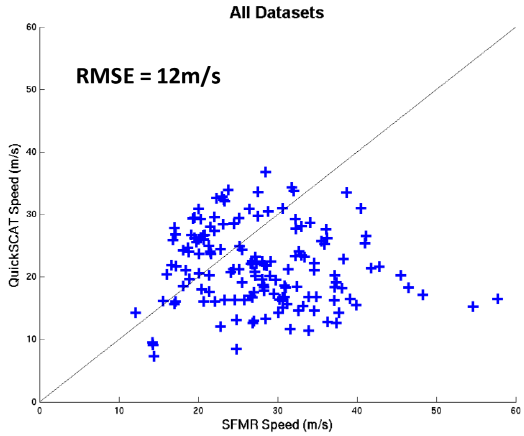


Figure 4: Comparison of in situ observations of wind speed during the 8 storms. Buoy versus SFMR is in the left (RMSE = 9 m/s) and QuickSCAT versus SFMR (RMSE = 12 m/s) is on the right. Note that both of these have worse RMSE than the SAR-derived wind speeds in Figure 3.

The wind estimation code is being readied for transition to CSTARS to run operationally during the ITOP experiments.

IMPACT/APPLICATIONS

If successful, the resulting system may significantly improved predictions of storm tracks and storm strength at landfall. This would have a large impact on coastal regions.

RELATED PROJECTS

There are no ongoing related projects that are closely identified with this project.

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